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Chapter 1

Introduction

In recent years, the deployment of 5G/Beyond5G and C-V2X (Cellular Vehicle-to-Everything) networks has made it possible to obtain a better scenario for the deployment of real-time safety applications [1]. Thanks to reducing delays and establishing different architectures, information can be easily and safely exchanged between different actors on the traffic routes [2]. These new technologies allow different modes of communication networks to connect not only cars but also different types of VRUs (Vulnerable Road Users).

In fact, in this type of network, it is possible to dispense with equipment dedicated to establishing vehicle networks (as was formerly used in the IEEE 802.11p protocol), allowing smartphone's use to constitute the network structure. The usage of C-V2X through smartphones also poses a series of challenges to consider. One of the main challenges is managing congestion environments of the communications network, as the number of devices connected to the network can increase significantly. Considering that the densities of devices present in crowds of people arises an unprecedented challenge. To tackle the device crowding problems such as over signaling and networks collapsing, it is possible to propose different architectures and device groupings [3].

This report aims to show the state of the art of a topic directly related to the doctoral thesis proposal. For this purpose, a critical and exhaustive review of recent articles published in journals and conferences of significant impact and recognized by the international scientific community is carried out. The remainder of this document is organized as follows: Chapter 2 is a critical and exhaustive study of the literature agreed upon with professor advisor. Chapter 3 discusses and critically analyzes the possible research gaps have not been covered or are posed as future challenges. Finally, Chapter 4 provides the work plan for the development of the doctoral thesis.

Chapter 2

State of The Art

Nowadays, it has been possible to observe a substantial increase in the interest in integrating new wireless access technologies in developing Intelligent Transportation Systems Applications. The new proposals and standardization have succeeded in expanding the use cases and performance of the information service related to intelligent and efficient transportation management. In fact, wireless access networks have been considered a key piece in realizing applications that are on ITS.

One of the most important advantages of the use of wireless networks in the traffic context, is that the information collected by both motor vehicles and infrastructure can be shared with the different users of the traffic network. This corresponds to the information collected individually by sensors in modern vehicles, as well as in the equipment installed in the infrastructure of the traffic roads. This involves new challenges that have been addressed mainly from a sensor fusion approach where the main idea is to share obstacle detection by vehicles with their environment. Thanks to this, the concept of Collective Perception has been defined [3], where one of the most important challenges corresponds to dealing with communication channel overload as well as redundant information reporting in the vehicular context.

Finally, one of the aspects to be addressed by the cooperative perception corresponds to the detection of vulnerable road users such as pedestrians, cyclists, electric scooter riders, and motorcyclists, among others. This has started to become an important feature in autonomous driving vehicles. The state of development for this type of system is very recent, so under the proposed objectives for the doctoral thesis, it is essential to conduct a comprehensive literature study related to the collective perception service directly related to vulnerable road users.

2.1 Collective Perception Service

First, a search is done for articles related to the concept of collective perception service. This service is in the standardization stage by the ETSI [4]. Additionally, reports considering the inclusion of VRUs within their studies or contributions are sought. It is possible to discover some papers that contribute from the literature review to establish the state of development of this service. The authors in [3] perform an extensive study on the releases from 3GPP for the implementation of 5G-V2X. In addition, they can take the information from the different definitions held in releases 14 and 16 and deliver precise details on the technologies involved, challenges, features, requirements, design, and technologies. Something to highlight in their study corresponds to the analysis of use cases where they specifically mention in the use case "UCC3: Cooperative safety" the following:

> "UCC3 is mainly concerned with protecting Vulnerable Road Users (VRUs), this can be done by detecting the presence of VRUs using a local sensor or camera or radar or using a positioning system or using the communication system. Another way to detect the presence of VRUs is by using their cellular phone information if the VRU holds a smartphone or a cellular communication device."

It can be observed that the use of smartphones in VRUs is proposed for the detection of these VRUs in the vehicular context. However, after establishing this use case's goal, the need to implement it in new technologies is mentioned. Surprisingly, they do not include the evaluation and design of new ways to warn the presence of VRUs using the communications network, discarding how much progress could be made in this area, such as the grouping of VRUs to establish resource allocation for this security message traffic. In the emerging needs of this case, they give importance to the inclusion of new sensors for the recognition of VRUs, discarding the active role of this type of user on the communications network.

On the other hand, in [5] it is possible to evidence an extensive and exhaustive research work related to literature related to the state estimation and motion prediction of vehicles and vulnerable road users for cooperative autonomous driving.

In this study, several proposals are detailed in the direction of VRU and vehicle detection in transit roads, considering this task as a primary one in the development of environment discovery capabilities of autonomous vehicles. In the first instance, the study describes the different sensors, methods, and techniques for detecting VRUs or animals. About the detection of cyclists and pedestrians, the study mentions the following:

> "More research is still needed in this area (Pedestrian, Cyclist and Vehicle Detection) since the mAP (Mean Average Precision) of the current methods, especially when it comes to pedestrians and cyclists that are more vulnerable and frequently disobey traffic laws, is far lower than 90%".

It should be noted that the study makes little mention of the possibility of pedestrians and cyclists being able to participate in the communication network; the focus of the study in question is strongly related to the different sensors deployed in the vehicles and other methods to exploit them.

Thanks to the two works mentioned above [3, 5] it is possible to access many proposals that are highly related to the object of study that supports this report. Both works allow us to understand many technologies, methods, and techniques for VRU detection and how different challenges associated with implementing and developing these systems originated.

Continuing with the literature review, in [6], the authors propose VRU detection, where it is established that they can connected with motorized vehicles over the IEEE 802.11g protocol. Additionally, the information coming from sensors deployed in each car is exploited, and techniques for the fusion of the information received by each vehicle are proposed. This study shows that an ideal fusion between perception and V2P communication should benefit from both systems. In fact, in Figure 2.1 a overall cooperative protection system description and a flow chart of fusion between perception and V2P communication are shown. Furthermore, consideration should be given to the context in which the detection occur (LOS or NLOS).

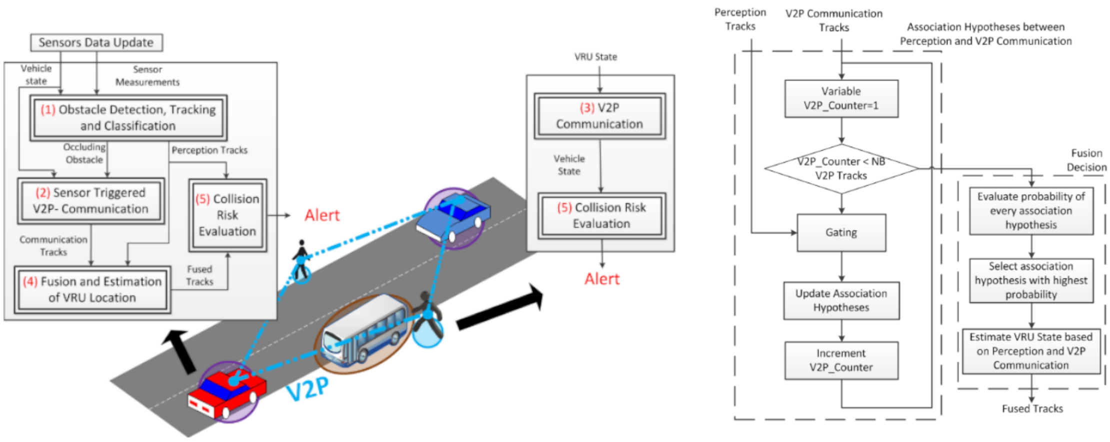

Figure 2.1: Cooperative protection system description (left) and flow chart of fusion between perception and V2P communication (rigth). Source: [6]

Additionally, this article performs evaluation in empirical experiment and contrasts it with theoretical models. Finally, it is necessary to indicate that this work does not consider any scheme or assumption about the grouping of VRUs or motor vehicles.

Subsequently in [7], the authors propose a system architecture that, based on collaborative information between vehicles and the infrastructure, can deploy applications such as track change warnings, among others application. This paper is strongly related to Cooperative Autonomous Vehicles (CAV). From this system the VRUs are considered as objects or non-cooperative users to be included in the information shared between vehicles. It uses the ETSI-ITS G5 standardization. The aim of this article is to describe the V2X solutions adopted by the EU funded project H2020 MAVEN (Managing Automated Vehicles Enhances Network)[1] Although, new technologies are arising the possibility to the VRUs be an active road user, the authors in [7] discard this feature for VRUs on the vehicular network context. The architecture proposed in the work detailed above is shown in Fig 2.2.

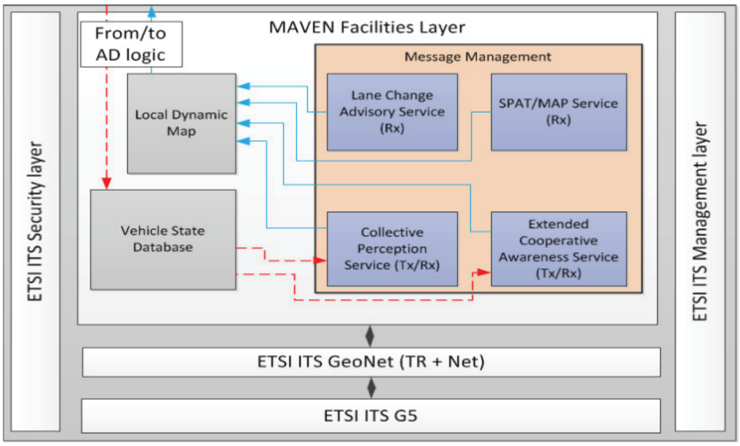

Figure 2.2: MAVEN CAV communication architecture. Source: [7]

On the other hand, in [8], the authors present an approach to cooperative tracking of cyclists using smart devices and infrastructure-based sensors. Although the study does not establish a specific technology for the exchange of information be-

[1] http://www.maven-its.eu/

tween the infrastructure and cyclists, the authors refer to the use of an ad-hoc network for the reception of variables associated with the cyclist's movement, such as speed (see Figure 2.3) for the infrastructure to track it. This work is mainly oriented to the theoretical analysis of how to track the VRU from infrastructure arranged in an intersection equipped with a stereo camera, so there is uncertainty if the study could be modified at the time of its implementation. However, they propose using a more realistic communication network model in their future work. Finally, it is not mentioned what is intended to be done with the VRU tracking, if only updating a database or if it is expected to transmit this information with the rest of the vehicles in the communications network. Then, in [9], the authors discuss

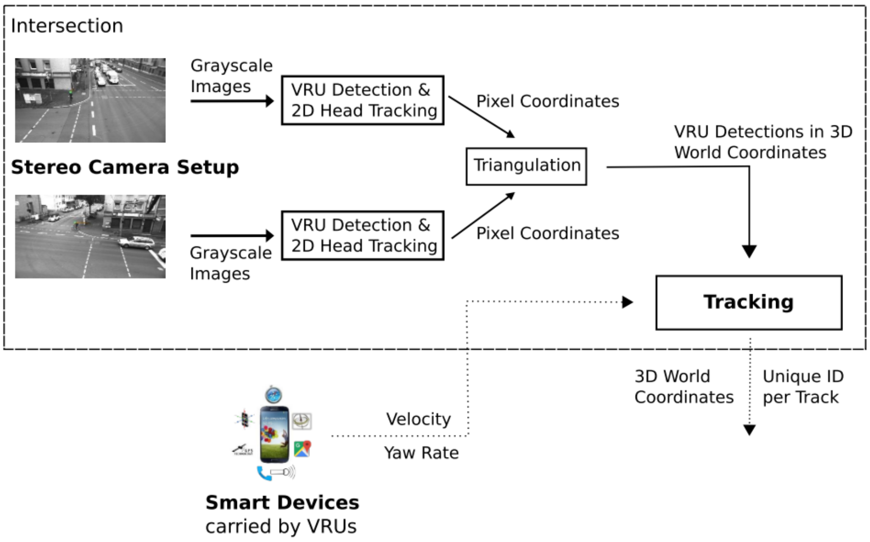

Figure 2.3: VRU tracking based on infrastructure and smart devices. Source: [8]

about the implementation of cooperative perception message generation rule, which aims to share obstacle discovery with vehicles in the neighborhood. An analysis is performed using traffic and communication network simulation where differences are evidenced when establishing dynamic message generation policies over time in contrast to fixed frequency message generation policies. It should be noted that they also evaluate the impact of these rules on high and low denial of service scenarios.

Finally, they establish a metric to measure the collective awareness of discovered objects. In addition to evaluating the performance of the communication network using the dynamic and static rules approach. In Figure 2.4, it is possible to observe how there are different levels of awareness in each of the evaluation cases, watching more significant differences when there is a greater distance between the obstacles and the vehicle that discovers them. At the same time, it is evident how the use of these rules directly impacts the performance statistics of the communications network, e.g., the packet delivery ratio (PDR). Finally, in this work, a passive role is given to the VRUs, and they will not participate in the exchange of cooperative perception messages.

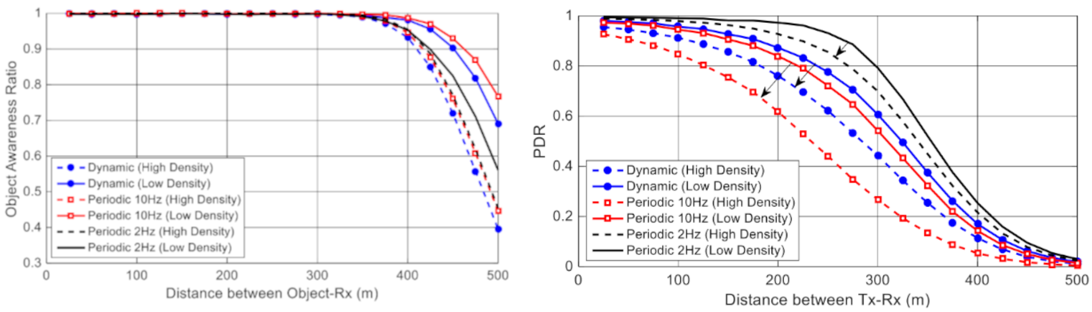

Figure 2.4: Object Awareness Ratio as a function of the distance between the detected object and the vehicle receiving the CPM (Left), PDR (Packet Delivery Ratio) as a function of the distance between transmitter and receiver (Right). Source: [9]

In much the same way as the previous article, in [10], the authors contribute within the invention of a set of generation rules for the Collective Perception Service, with which seek to handle the trade-off according to two important aspects in the performance of vehicular networks:

- Provided service quality for receiving Intelligent Transport System stations, in terms of the number of known objects as well as the update frequency per unique object known.

- the generated network load on the employed radio channel.

Unlike the authors in [9], more complex generation rules are established that consider the following characteristics of the detected object: novelty, distance, speed, and age. In addition, they include in their system the segmentation of cooperative messages to reduce the radio channel load and thus improve the statistics of the communication network.

On the other hand, in [11], the authors focus mainly on the fusion of information coming from other vehicles that are connected through 802.11p with which VRU detection is performed. It does not consider connection technology for VRU. Furthermore, the authors describe a flexible end-to-end system simulator that can evaluate such cooperative mapping strategies in complex road driving environments. As is shown in Figure 2.5, the proposed system in this work needs an infrastructure where the information or environment maps is sent to the station. Gathering the map from every vehicle in the surrounding area for the base station it is possible run VRU or obstacle detection's.

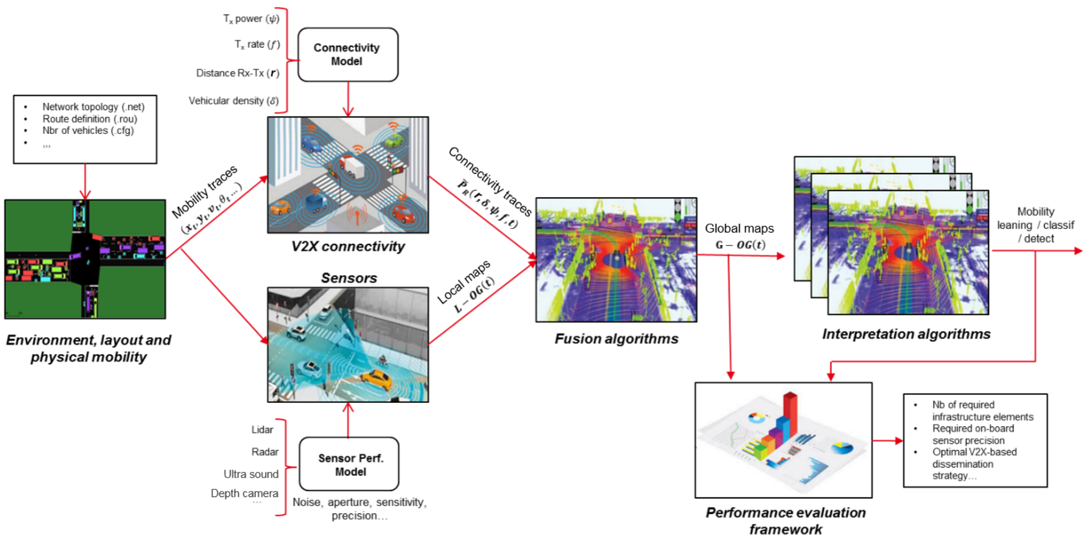

Figure 2.5: Dataflow for the proposed system Source: [11]

Continuing with the literature review, in [12], after a literature study related to the integration of VRUs in the context of wireless communication network development and the technologies used for this purpose, they evaluate - using simulations - the implementation of rules for the generation of messages from VRUs, taking into consideration their dynamics. Therefore, they consider the VRU active within the context of the communication network. For evaluating their proposal, they use a simulation of an intersection as shown in Figure 2.6. Within the discussion of their results, they highlight the importance of VRUs' active role in communications. In addition, it is evidenced - supported in other works - that the use of devices in VRU would significantly increase the load on the communication network, so it mentions some of the efforts to deal with the congestion problem, among which are the creation of reception-only modes, contextual transmission, and VRU clustering.

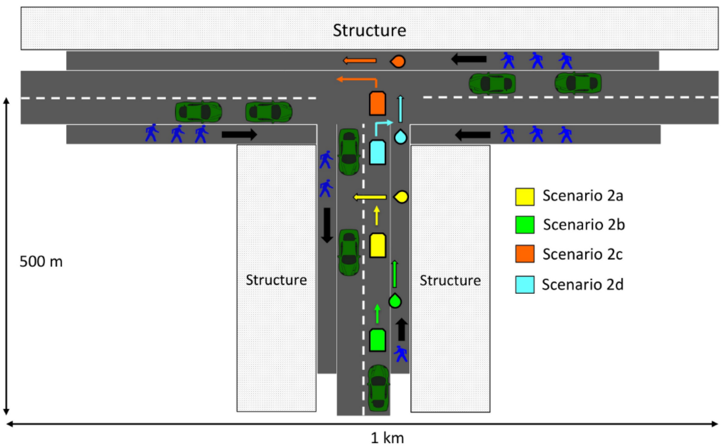

Figure 2.6: Simulation scenario, source: [12]

Then, in [13], Using The Age-of-Information (AoI) metric, the authors evaluate a system where VRUs send messages over the C-V2X scheme, i.e., from their devices to a base station (see Figure 2.7). With this, they evaluate the performance of metrics such as packet inter-arrival time for detecting these users by motor vehicles. Additionally, they establish a considerable improvement over the metrics discussed above by using a Multiple-access Edge Computing MEC architecture. All about the performance evaluation has done over analytical models.

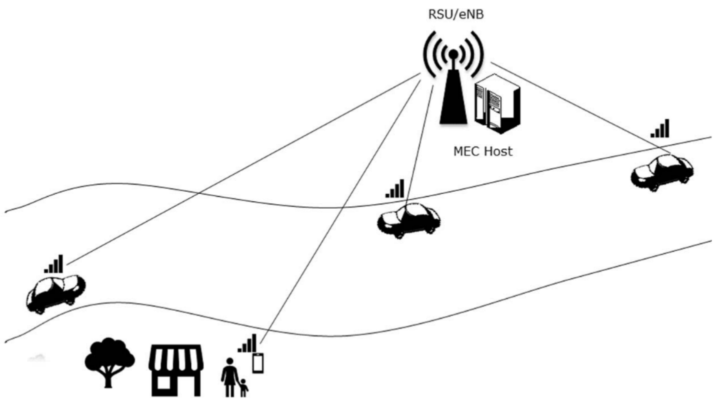

Figure 2.7: Evaluation scenario. Source: [13]

Subsequently, in [14], a system called AutoC2X to enable cooperative perception using OpenC2X for autonomous vehicles based on Autoware is shown. The proposed system (see Figure 2.8) is first tested in software implementation contexts and then field-tested with actual equipment. This proposal's full development focuses on providing better environmental information to autonomous vehicles. The results show that they can reduce the delivery times of collective perception messages up to 100[ms] in the worst-case scenario. They consider VRUs as passive since they are taken as obstacles. The experiments involve infrastructure such as a roadside unit to obtain environmental information reported by other autonomous vehicles.

In [15], the authors present a system for generating collective perception messages based on the implementation of sensor-equipped infrastructure for VRU protection. This covers areas with blind spots where vehicle sensors have poor performance. It should be noted that in this work, the authors present the design of their proposal (see Figure 2.9) in addition to performing empirical evaluation in a real experiment and on simulations. The results show that the proposed system meets the expected objective, however under the large-scale assessment, the authors identify a lack in

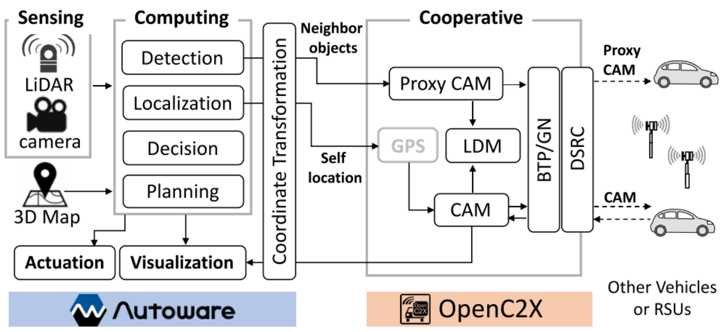

Figure 2.8: Architecture for the proposed system. Source: [14]

the delivery of information about the collective perception messages due to highly congested scenarios; for this, the authors propose to give priority to the link for I2V than for V2V in what is known as resource allocation.

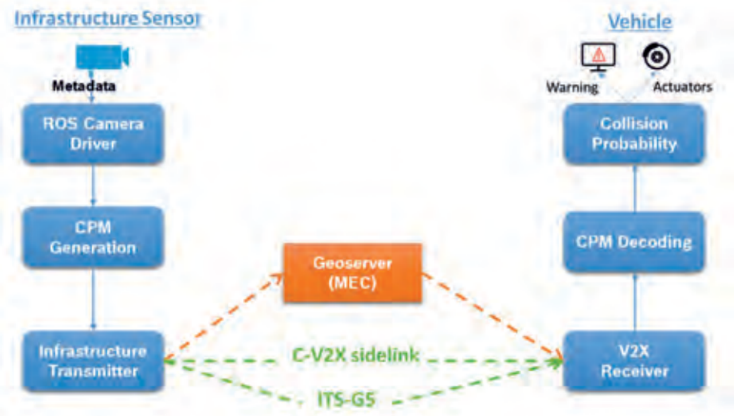

Figure 2.9: System architecture of the VRU protection use case. Source: [15]

On the other hand, in [16], the authors analyze the inclusion rules of person-like objects in a large-scale simulation study, demonstrating that the exchange of cooperation messages can significantly improve people's awareness with little additional use of channel resources. For adding a new person or VRU to the cooperative perception messages, they use the scheme shown in Figure ??, which is taken from another publication. The main contribution of this work lies in the large-scale simulation of the evaluation scenario. In the paper, they conclude that using the rules improves the congestion conditions of the channel when the number of obstacles to be discovered increases.

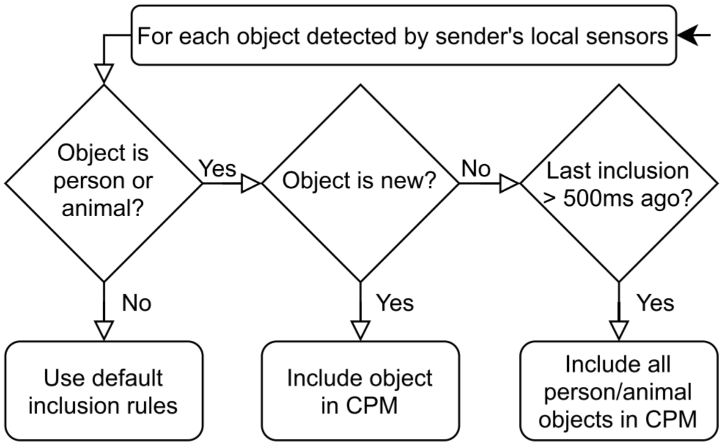

Figure 2.10: Inclusion rules for objects of type person or animal currently defined in TR 103 562 (ITS standardization) Source: [16]

Then, in [17], the main contribution from the authors of this work is the generation of virtual pedestrians that realistically avoid obstacles, providing a platform to accurately and efficiently test autonomous vehicles in pedestrian areas. In this way, it provides a tool for the entry of autonomous vehicles and how the latter can interact with pedestrians. It should be noted that this work considers not only individual people but also studies cases of interaction with groups of people moving in pedestrian zones. The latter is relevant because it is one of the few articles that refer to the detection of not only individuals but also groups of people. In Figure 2.11, it is possible to observe a view of the simulation where pedestrians and an autonomous vehicle are arranged.

Authors in [18], propose an interactive traffic application based on robust connectivity of all traffic participants and intelligent infrastructure. As shown in Figure 2.12, the proposed application is based on an established architecture where different options for VRU and vehicle connection exploiting WiFi, BLE, and CV2X networks

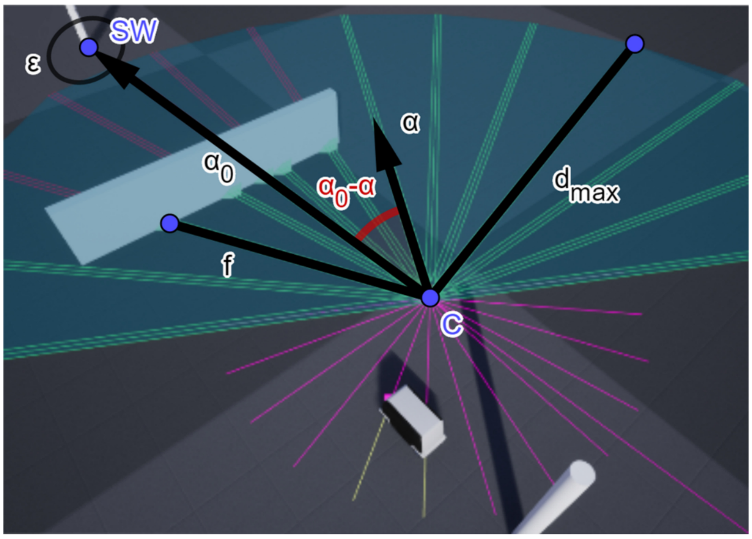

Figure 2.11: Simulation view of virtual pedestrian c in the vicinit of vehicle and an obstacle. Source: [17]

are considered. The application seeks to alert the presence of VRUs on the roads using sensors and cooperative perception messages. However, no evaluation of the proposed application is evidenced by simulations or experimental tests.

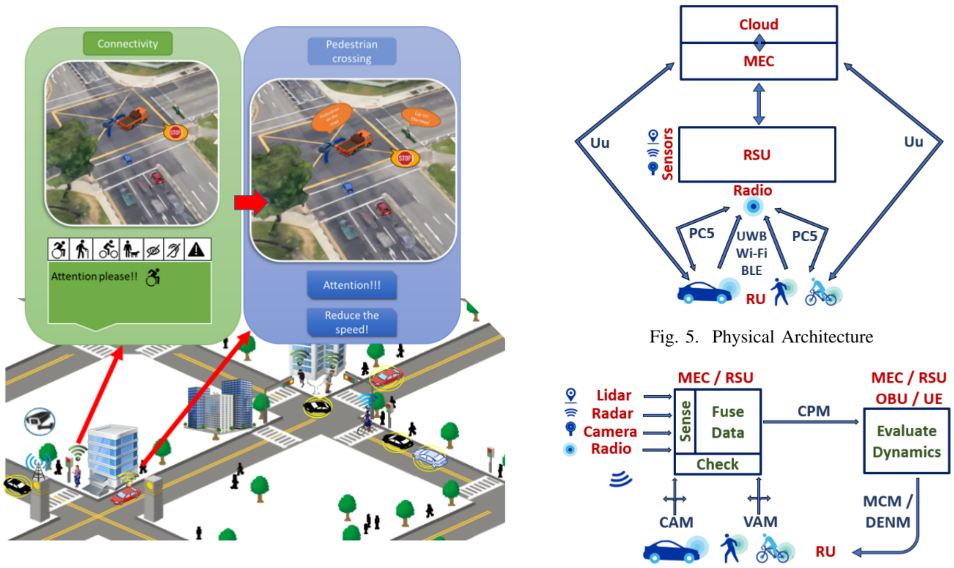

Figure 2.12: Interface Application usage in a traffic scenario and the proposed architectures. Source: [18]

Finally, in [19], the authors analyze, evaluate and compare rules for the inclusion of new obstacles recognized by sensors. These rules are focused on mitigating redundant information within the communication network in the vehicular context due to the reporting of the same object by two or more vehicles or infrastructure in its vicinity. From the analysis of simulations, the authors can implement the rules of mitigation of redundant information by taking four filters (see Figure 2.13) through which the data should be checked. The results show that implementing these rules positively impacts the communication network, decreasing the load on the communication network without compromising the vehicle's awareness of obstacles or VRUs. However, it is considered positive that the authors recognize that adjusting the rule parameters according to the load state of the communication network will increase its performance in terms of collective awareness and efficient use of network resources.

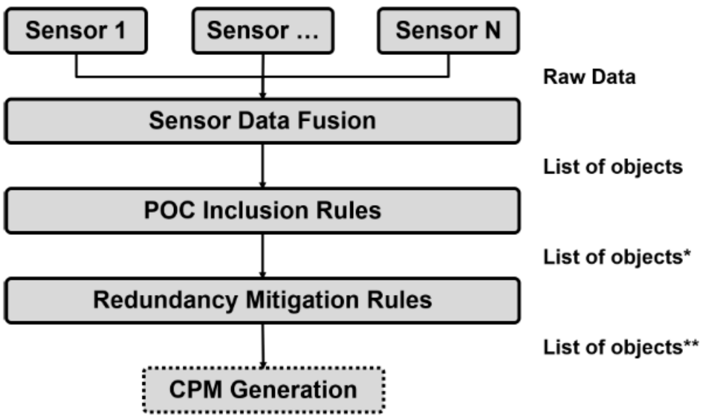

Figure 2.13: dataflow for the proposed system Source: [19]

Table 2.1: Comparison of all articles selected

Article	Sensors	Communications	Individual or group approach	Experimental Setting	Architecture	VRU	Year
Merdrignac, P. et al [6]	Laser Based on Cars	IEEE 802.11g	Individual VRU Cooperative Vehicles	Theoretical and Empirical results	V2P	Active	2017
Rondinone, M. et al [7]	Vehicle Sensors on board	ETSI ITS G5	Cooperative Vehicular Group Formations	-	V2I - V2V	Passive	2018
Reitberger, G. et al [8]	Stereo Camera in Intersection Infrastructure	Ad-hoc network	Individual VRU	Theoretical	P2I	Active	2018
Thandavarayan, G. et al [9]	Two sensor on Cars	ETSI ITS G5	Individual VRU Cooperative Vehicles	Simulations	V2V	Passive	2019
Garlichs, K. et al [10]	Sensors on Cars	ETSI ITS G5	Individual VRU Cooperative Vehicles	Simulations	V2V	Passive	2019
Da Silva, A. et al [11]	LIDAR and RADAR approach	802.11p	Individual VRU Cooperative Vehicles	Simulations	V2V-V2I	Passive	2019
Sewalkar, P. et al [12]	-	802.11p	Individual VRU Cooperative Vehicles	Simulations	V2V-V2P	Active	2019
Emara, M. et al [13]	-	C-V2X	Individual VRU Cooperative Vehicles	Theoretical	V2I - P2I	Active	2020
Tsukada, M. et al [14]	LiDAR	802.11g	Individual VRU Cooperative Vehicles	Simulations and Empirical Results	V2I	Passive	2020
Schiegg, F. et al [15]	Camera in Infrastructure	C-V2X ETSI ITS G5	Individual VRU Cooperative Vehicles	Simulations	I2V-V2I	Passive	2021
Willecke, A. et al [16]	RADAR	ETSI ITS G5	Individual VRU Individual Vehicles	Simulations	V2P	Active	2021
Jan, Q.H. et al [17]	Camera	-	Individual and grouping VRU Individual Vehicles	Simulations	-	Passive	2021
Militaru, A.V. et al [18]	Camera LIDAR RADAR	BLE, WiFi UWB, V2X-PC5 G5	Individual VRU Individual Vehicles	Architecture	V2I-V2P-P2I	Active	2021
Delooz, Q. et al [19]	Two Radars	ETSI C-ITS G5	Individual VRU Cooperative Vehicles	Simulations	V2I-I2V	Passive	2022

Chapter 3

Discussion and Future Work

According to the critical and exhaustive study carried out in this report, it can be evidenced the explosive importance that VRUs have taken on the development of standards that include the presence of VRUs and consider them as a critical element for their coexistence with autonomous and motorized vehicles.

It is important to note that less than half of the articles studied consider an active role for VRUs. Works from which it is possible to observe a significant increase in the awareness of this type of user on the roads.

According to the research gaps that this study can establish, it highlights the high dependence that all these proposals have the standardization processes by institutions such as IEEE, ETSI, and 3GPP, among others.

There is possible evidence of the lack of grouping management in these systems for autonomous or motorized vehicles and VRUs. Considering that if there is an active role of the VRUs, this impacts the load of the communications network significantly and where the grouping of this type of users could benefit the use of the radio channel established for information exchange.

In future work, it is proposed the inclusion of different rules established in state of the art and how these can be affected when we work with vehicular clusters.

Chapter 4

Work Plan

This chapter presents the work plan related to the development of the doctoral thesis in the Table 4.1. It is important to consider that the next milestones to be followed for the completion of the doctoral thesis and the obtaining of the doctoral degree are detailed. However, it is necessary to mention that there is a previous work that supports the implementation of the proposal. This previous work corresponds to the publication of an article [20] detailing how it was possible the inclusion of pedestrians in the discrete event simulation environment that considers both mobility models of motor vehicles and vulnerable road users VRU, as well as the exchange of messages over a wireless communications network supported by IEEE 802.11p. Additionally, the impact of the inclusion of rules for message generation on vulnerable road users and the relationship with the awareness of vulnerable road users by motor vehicles was evaluated in [21].

Table 4.1: Work plan Ph.D. proposal

Task \ Period	Oct 2022	Nov 2022	Dec 2022	Jan 2023	Feb 2023	Mar 2023	Apr 2023	May 2023	Jun 2023	Jul 2023	Aug 2023	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024
1. Writing Comprehensive Exam Report	**x**																
1.1 Comprehensive Exam Defense		x															
2. Ph.D. proposal preparation		**x**	**x**	**x**													
2.1 Unify the state of art including previous research		x															
2.2 Define scope and objectives according to deadlines.		x															
2.3 Writing Hypothesis and Methodology			x														
2.4 Ph.D. proposal defense				x													
3. Survey article preparation and submission to a Journal					**x**	**x**											
4. Implement C-V2X / LTE for connected VRU and its detection from motorized vehicles using both LTE and IEEE 802.11p						**x**	**x**	**x**	**x**								
4.1 Implement in simulation environment different algorithms for VRU swarms/clustering						x											
4.2 Implement in simulation environment different densities scenarios							x	x									
4.3 Evaluate performance and awareness of IEEE 802.11p and LTE modes for VRU detection and dissemination from motorized vehicles under different densities.								x	x								
4.4 Evaluate performance and awareness of IEEE 802.11p and LTE modes for VRU detection and dissemination from motorized vehicles under different swarm algorithms.									x								
5. Doctoral seminar										**x**							
6. Desing of Intelligent System to manage different architecture or communications modes, density scenarios and swarms algorithms election according to enhance VRU awareness										**x**	**x**	**x**	**x**				
6.1 Desing a module for density detection through LTE and 802.11p										x	x						
6.2 Desing a module for architecture or technology communication election for VRU detection and dissemination from motorized vehicles											x	x					
6.3 Desing a module for clustering algorithms election for VRU connected												x	x				
7. Comprehensive evaluation of the Intelligent System													**x**	**x**			
7.1 VRU awareness evaluation													x				
7.2 Networks Statistic evaluation														x			
8. Preparation and submission of a research article to show the proposed system in a journal														**x**	**x**		
9. Ph.D. Thesis Defence preparation															**x**	**x**	**x**
9.1 Writing Final Document															x	x	
9.2 Ph.D. Thesis Defence																	x

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